Base Drag Reduction Caused by Riblets on a GAW(2) Airfoil

Channa Raju* and P. R. Viswanath¡ *National Aerospace Laboratories,*
Bangalore 560 017. India

Nomenclature

- base drag coefficient, [$C_{p,}(r/c)$]
- total drag coefficient
- pressure coefficient. (p - p,jlq.

. - base pressure coefficient, (p_b - $_{x}$
airfoil chord
riblet height

- = local static pressure
- = freestream static pressure
- = freestream dynamic pressure = trailing-edge thickness
friction velocity
= distance along the chord
= distance normal to tunnel axis =
angle of attack

· (CD61,1r~ C_D
kinematic viscosity

Introduction

AMONG various methods explored for turbulent drag reduction on aerodynamic surfaces, riblets have beer the most promising.' As much as 4-8% of viscous drag reduction has been reported for simple two-dimensional configurationsPlastic sheets with symmetric v-grooves (manufactured by the 3M Co.) have been employed widely in research- Assessment of viscous drag reduction on two-dimensional airfoils. both at low and transonic speeds, has been reported as well.¯ Excellent reviews on the subject covering aspects of drag reduction and flow structure are contained in Refs. 1 and 7.

There have been very few attempts exploring the fuse of giblets in separated flows, either from the point of view of drag reduction or separation control-[r'°] Recently. Krishnan et al.' *showed that riblets actually increase the base drag (about 8.7* on a long axisymmetric body with a blunt base at low speeds: the base diameter was about four times the boundary -layer thickness ahead of the base corner- They used 3M riblet sheers and systematically studied the effect of h+` on base pressure. They also speculated that, while riblets caused an increase in the base drag for a large-scale separated flow (like on the axisymmetric blunt base'), the effect could be favorable on an airfoil with a blunt trading edge, which is a case of a small-scale separated flow.

The present investigation was undertaken specifically to assess the effect of 3M riblets on the base pressure of an airfoil with a blunt trailing edge. Experiments were made at low speeds on a 13.6% thick GAW(2) airfoil model, which has a trailing-edge thickness ratio of 0.5%. The results show very clearly that the base drag reduction of an engineering value can be achieved for the optimized riblet geometry.

Experiments

Facility and Model

The experiments were conducted in a 300 X 1500 ntm boundary-layer tunnel. The GAW(2) airfoil model. with a r of

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*Scientist. Experimental Aerodynamics Division.

tH d. Experimental Aerodynamics Division. Associate M10[1]
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600 mm and a span of 300 mm, having a trailing-edge thickness of 3 mm, was mounted vertically in the test section. The „odel was instrumented with 38 static pressure taps of o.d. 1.2 mm ~n the upper and lower surfaces. The base pressure was measured and averaged using three ports distributed along the vicin'iy of the midspan of the model.

hfeasurements

The tests were performed at a freestream velocity of 30 nil s, providing a chord Reynolds number of f x 10'. The boundary layer on the top and bottom surfaces ***of the model was*** tripped at 10% chord from the leading edge using a sandpaper strip (24 grade, 30 mm wide).

Riblet films with a height of 0.076 and 0.152 mm were used in this work; they were applied between 0.1 and 0.96c on both the top and bottom surfaces. Streamwise variations of ii' calculated using an integral turbulent boundary-layer code'" for the measured pressure distributions on the airfoil upper surface at a = 0 and 6 deg are displayed in Fig. 1. The riblet films with h = 0.076 and 0.152 mm appear optimum at a = f) and 6 deg, respectively, considering viscous drag reduction.

The Freestream dynamic pressure, model surface. and the *case pressures were measured using three* micromanometers supplied by Furness Controls, UK. The total drag was determined from the picot and static measurements in the wake using the method of Jones," A constant temperature hot-wire anemometer was used to assess the existence of vortex shedding behind the base. Measurements of model static pressures and picot profiles in the wake were made over an angle-ofattack range of -2 to 6 deg. The reference configuration for determining drag reduction was the smooth airfoil model without the riblet and with the same transition trip.

Accuracy of the Measured Data

The uncertainties in the measured data estimated using the methodology of Kline and McClintock'" and taking into account repeatability are

AC, = ~0.0035C,, AC, = !0.015C"

Two Dimensionality

The two dimensionality of the flow was assessed by employing the two-dimensional momentum integral in the wake. Picot profiles for the smooth model (without riblets) at three streamwise locations in the wake (xlc = 10, 2.5, and 3.01 were measured for determining the total drag. Excellent constancy of drag coefficient (within the estimated uncertainty) was observed to suggest good mean flow two dimensionality in the experiments."

Results and Discussions

Surface Pressure Distributions

The measured surface pressure distributions on the airfoil. both with and without the riblets, revealed" that the effects of riblets on C_A distributions were very small (as in many earlier studies"`), which suggests that the pressure drag is virtually unaltered because of riblets.

Base Pressure and Base Drag

The base pressure coefficient for the basic airfoil (without riblets) is positive at all a, indicating a base thrust (Fig_ 2). It is interesting to note that the base pressure progressively increases with riblet height in the a range considered. These results are in contrast with those measured on an axisymmetric blunt base at low speeds." As may be expected, the base drag coefficient is obviously negative because of base thrust, and its magnitude increases further with riblet height. The ratio of

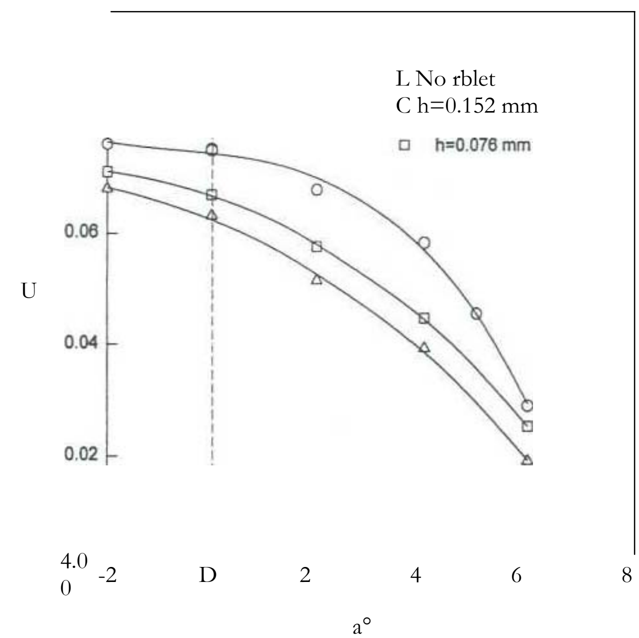

Fig. 2 Variation of base pressure coefficient with incidence.

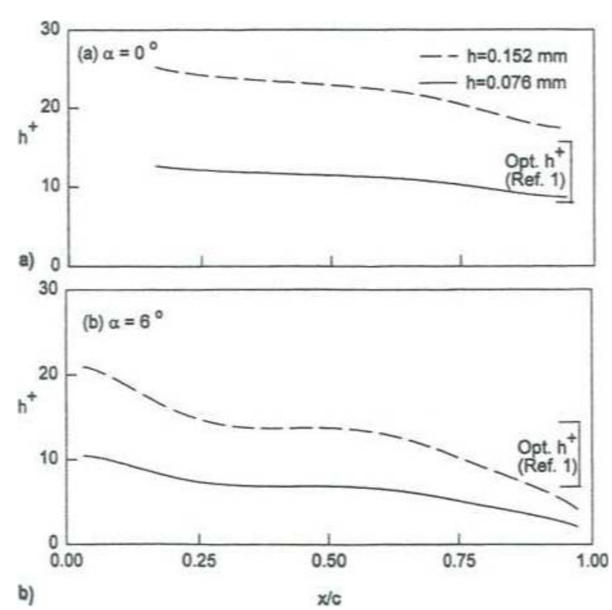

Fig. 1 Variations of h` on **upper surface** of GAW(2) airfoil.

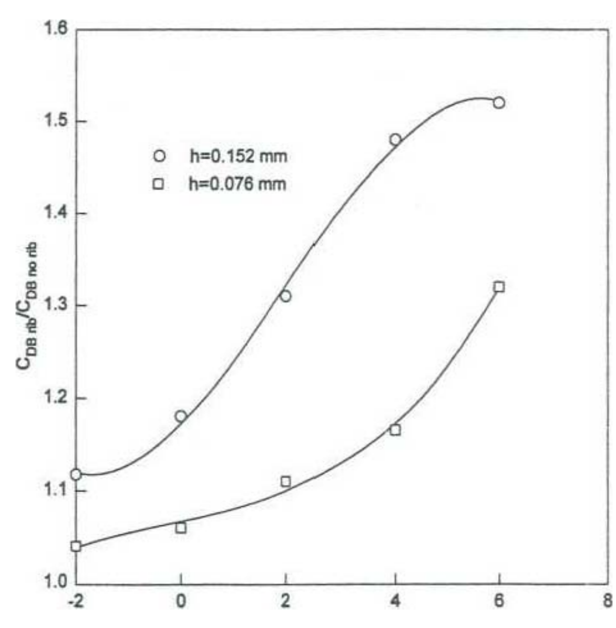

Fig. 3 Variation of normalized base drag with incidence.

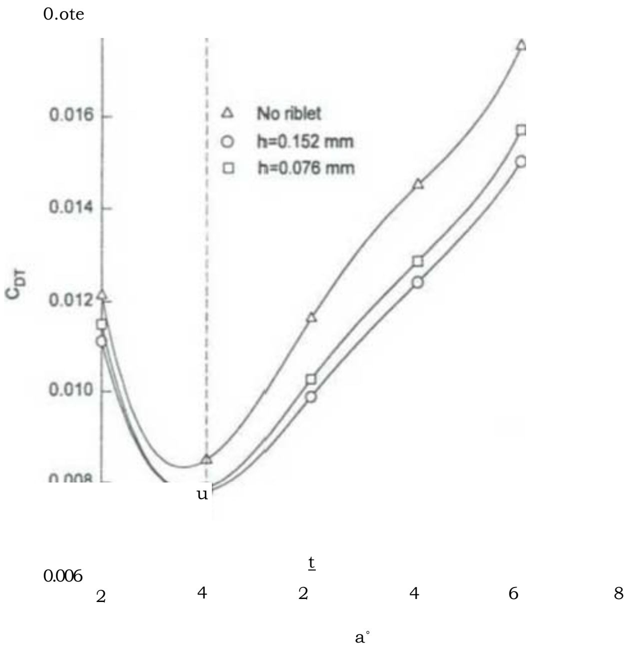

Fig. 4 Variation of **total drag** coefficient with incidence.

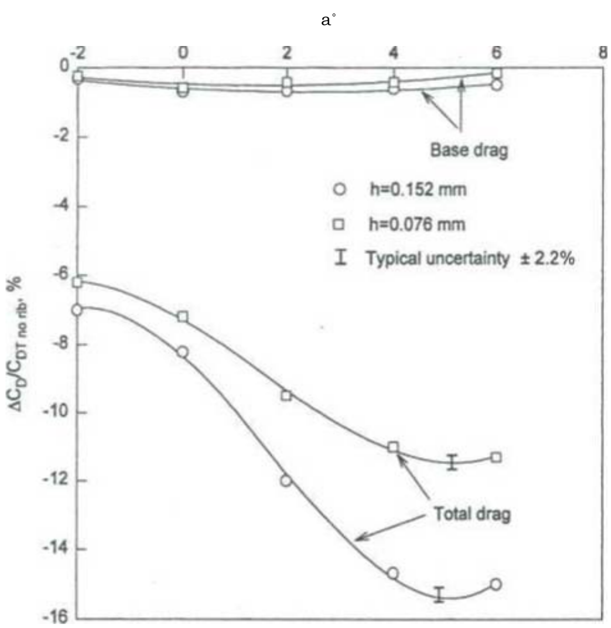

Fig. 5 **Total drag** and base drag reductions with incidence.

base drag coefficient with riblets relative to no riblets is shown plotted in Fig. 3. The increase in base thrust is as high as 5090 at a = 6 deg for the riblet height of 0.152 mm. The effectiveness of riblet films with h > 0.152 mm could not be assessed because they are not manufactured currently by 3M Co.

Total Drag

Results of measured total drag coefficient (C„ r), both with and without rib€ets, are plotted against airfoil angle of attack in Fig. 4. The riblet film with a height of 0.152 mm has the lowest drag consistent with the optimum h' variation (discussed in Fig. 1). Figure 5 displays the results of percentage total drag reduction as well as base drag reduction (relative to the smooth baseline configuration); the normalizing factor for both total and base drag reduction is the total drag coeffcient of the smooth airfoil at each a. The increasing trend of total drag reduction with a is a feature already observed by Sundaram et al.' and Subaschandar et al.,[s] ' and has been attfibuted to the increased effectiveness of riblets in adverse pressure gradients. The maximum base drag reduction (equivalently an increase in base Ihmst). of about 0.7% of the total drag ob_ served fair h = 0_ 152 mm, is nearly constant with re.

Possible Flow Mechanisms

Having observed the increase in base pressure because a riblets, it is appropriate to speculate on possible flow mechanisms that may he responsible for the same. Measurement, using a hot-wire probe in the near-wake showed no evidence of vortex shedding For the baseline as well as the ribbed airfoil configurations, suggesting that the increased base pressure is obviously caused by mean Flow changes because of riblets, h is well known, e.g., Refs. I, 3, and 7. that riblets lead to lower boundary-layer displacement thickness (S*) and, therefore. the effective base height (including u* effect) is smaller cornpared with the smooth airfoil. and an increase in base pressure eaa be expected." In the context of base fow dynamics. it isgererally known' -" that the base pressure depends on the de_ velopinent of the free shear layer, which in turn depends as the initial boundary-layer conditions just ahead of the bas; Earlier studies" revealed that the near-wall flow is strongiv affected by riblets, which includes a reduction in turbulent i-_ tensities (as much as 10-2O%)' `-'" and Reynolds shear stre.s. e.g., about 15% in the experiments of Walsh" and Suzuki and Kasagi.'° It would therefore seem likely that the combination of lower (mean) velocity gradient and reduced levels of turbulent intensities and shear stress in the wall region of the approaching boundary layer (ahead of the base plane) will Cavorably affect the shear-layer development because the mixing zone is relatively short (comparable to the trailing-edge thickness). It is suggested that the increase in base pressure Is primarily influenced by the initial conditions of the boundary layer just ahead of the base because of riblets leading to (eel. atively) lower velocity along the dividing streamline of the shear layer and, hence, a higher base pressure'° in the presence of riblets.

Conclusions

It has been demonstrated for the first time that riblets can also provide a base drag reduction of engineering value t•n a blunt trailing airfoil at low speeds; the results further show that the base drag reduction is maintained up to an airfoil incidence of 6 deg. Although the base drag reduction is large (as much as 50% of the smooth airfoil base drag), its contribution as a fraction of the total drag in only about 0.7% because the base drag component itself is small on the airfoil. It is suggested that the increase in base pressure is a direct consequence of certain favorable changes in the boundary layer as a result of riblets ahead of separation; these include a lower effective base height of the airfoil (including boundary-layer displacement thickness) and reduced mixing in the free shear layer leading to lower velocity along the dividing streamline. It would be very informative and valuable to assess base drag reduction because of riblets on supercritical airfoils with a blunt trailing edge at transonic speeds, as well as to investigate, in d'taii. flow mechanisms responsible for the base pressure increase with these riblets_

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